Efficient Processing of Data for Locating Lightning Strikes

Time differences can be computed efficiently to subnanosecond resolution.

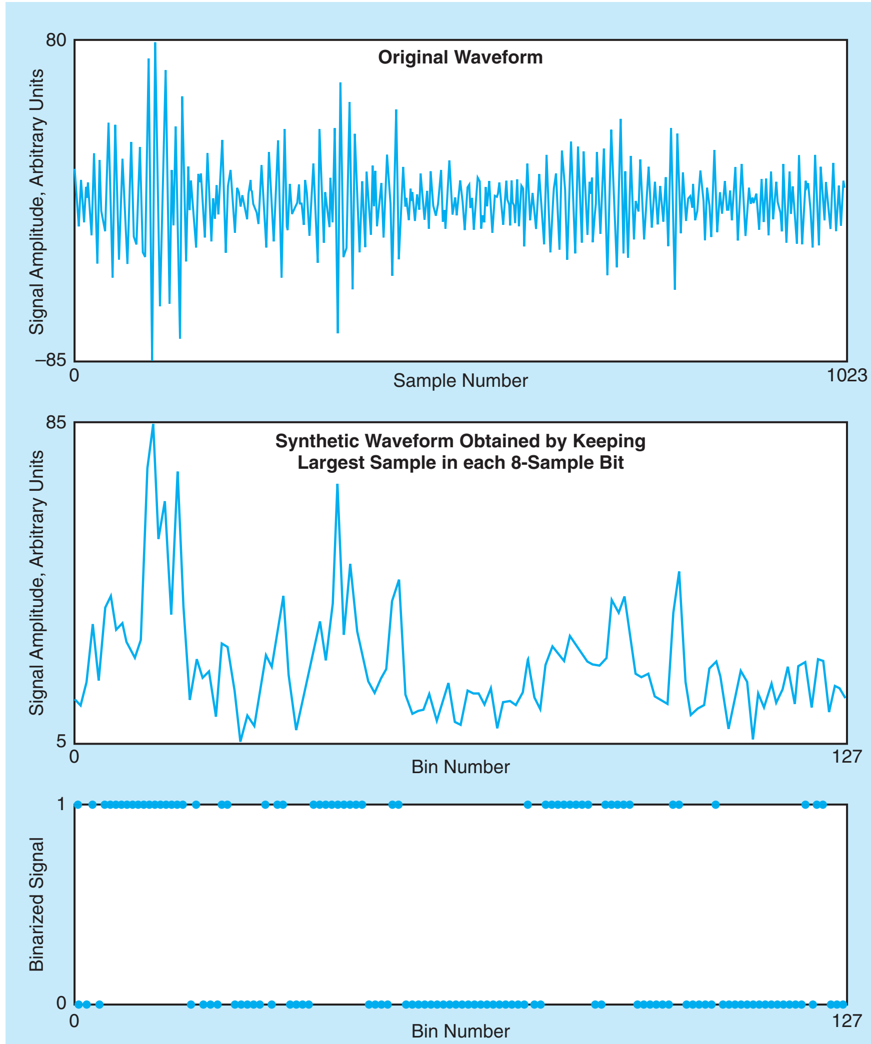
John F. Kennedy Space Center, Florida

Two algorithms have been devised to increase the efficiency of processing of data in lightning detection and ranging (LDAR) systems so as to enable the accurate location of lightning strikes in real time. In LDAR, the location of a lightning strike is calculated by solving equations for the differences among the times of arrival (DTOAs) of the lightning signals at multiple antennas as functions of the locations of the antennas and the speed of light. The most difficult part of the problem is computing the DTOAs from digitized versions of the signals received by the various antennas. One way (a time-domain approach) to determine the DTOAs is to compute cross-correlations among variously differentially delayed replicas of the digitized signals and to select, as the DTOAs, those differential delays that yield the maximum correlations. Another way (a frequency-domain approach) to determine the DTOAs involves the computation of cross-correlations among Fourier transforms of variously differentially phased replicas of the digitized signals, along with utilization of the relationship among phase difference, time delay, and frequency.

One of the two algorithms is a computationally efficient implementation of the time-domain approach. This algorithm is intended specifically for use in an LDAR system in which the antennas are located at spatial intervals of about 100 m, the receiver at each antenna digitizes the signal at a rate of 500 megasamples per second, the signal is processed in successive 1,024-sample (2.048-μs) time windows for the purpose of correlating it with 128-sample windows from the other antennas, and it is desired to compute 30,000 locations per second.

This algorithm includes the following steps:

1. Every 1,024-sample record is divided into 128 bins, each containing 8 consecutive samples.
2. The largest sample value within each bin is kept, and the other 7 samples are discarded, thus leaving 128 data points.
3. The average of the 128 remaining sample values is calculated.
4. Every sample value equal to or larger than the average is assigned a 1 and every sample value below the average is assigned a 0 (see figure).
5. The 128 resulting binary data are then stored as 16 bytes of 8 bits each.



A **Waveform Originally Sampled at 1,024 Points** is subsampled at peaks within 128 bins, then binarized.

6. Once the data from each antenna have been processed as described above, a bit-to-bit cross-correlation is performed between a 16-byte record from one channel and a 4-byte record from another channel. Because this is a bit-to-bit operation, it can easily be performed in real time by use of a field-programmable gate array (FPGA) integrated circuit. The result of operation 6 is a set of rough estimates of the cross-correlations.
7. Using the rough estimates as guides, finer estimates are obtained by calculating cross-correlations on the original digitized (but the binarized) sample data over a range from 16 samples before to 16 samples after the differential delay found from the rough estimate.

Whereas the computing power needed to generate the fine estimates by processing all of the original sample data is 3.44 gigaflops, the computing power needed to arrive at the fine estimates by way of this algorithm is only 122 megaflops. This amount of computing power lies within the range of available digital signal-processing integrated-circuit chips.

The time-domain algorithm described above cannot determine time differences to less than the 2-ns sample period. The other algorithm implements a frequency-domain approach to obtain higher temporal resolution. The frequency-domain algorithm includes the following steps:

1. The algorithm described above is used to obtain estimates of DTOAs to within

a resolution of 2 ns.
2. Waveforms from the various antennas are paired and temporally aligned with each other according to the 2-ns-resolution DTOAs.
3. The waveforms are windowed to prevent the introduction of extraneous frequency components.
4. A fast Fourier transform (FFT) is computed for each waveform. Because the receivers at the antennas operate in the 30-to-38- and 110-to-200-MHz frequency bands only, it is possible to limit the FFTs to these frequency bands, without loss of signal information, to reduce the computational burden.
5. Within each pair, the phase difference between the FFTs of the two signals is computed for each frequency. For each pair, the time difference that corresponds to the phase difference for each frequency is calculated, then an effective delay for the pair is calculated as a weighted sum of the time differences in all of the FFT frequency intervals.
6. For each pair, the effective delay is added to the starting 2-ns-resolution DTOA to obtain a more precise DTOA.

This work was done by Pedro J. Medelius and Stan Starr of Dynacs, Inc., for **Kennedy Space Center**. *Further information is contained in a TSP [see page 1].*
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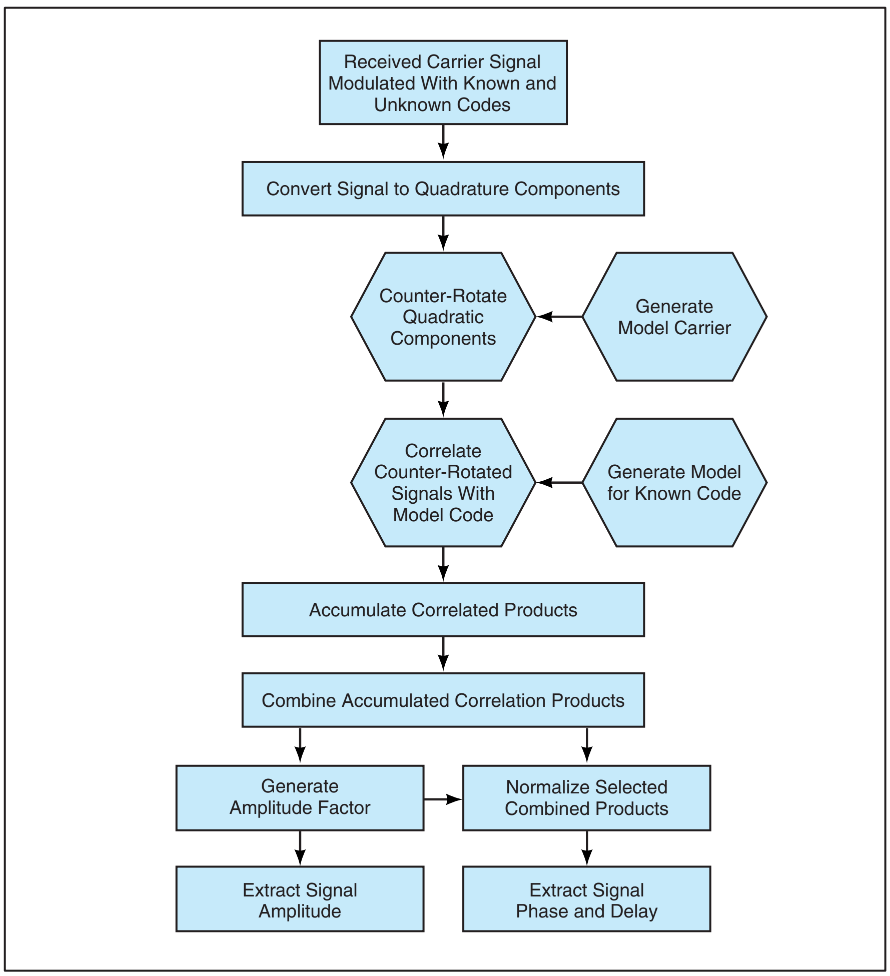
P-Code-Enhanced Encryption-Mode Processing of GPS Signals

This is an improved method of processing without knowledge of the encryption code.

NASA's Jet Propulsion Laboratory, Pasadena, California



P-Code-Enhanced Encryption-Mode Processing of GPS signals according the present invention involves this sequence of steps.

A method of processing signals in a Global Positioning System (GPS) receiver has been invented to enable the receiver to recover some of the information that is otherwise lost when GPS signals are encrypted at the transmitters. The need for this method arises because, at the option of the military, precision GPS code (P-code) is sometimes encrypted by a secret binary code, denoted the A code. Authorized users can recover the full signal with knowledge of the A-code. However, even in the absence of knowledge of the A-code, one can track the encrypted signal by use of an estimate of the A-code. The present invention is a method of making and using such an estimate. In comparison with prior such methods, this method makes it possible to recover more of the lost information and obtain greater accuracy.

The limitation on space available for this article precludes a description of the prior methods. However, a description of pertinent generally applicable aspects of GPS signals and signal processing is presented in the next three paragraphs because it is prerequisite to a meaningful summary of the present method.

Each GPS satellite transmits two L-band signals, denoted L1 (at a carrier frequency of 1.57542 GHz) and L2 (at a carrier frequency of 1.2276 GHz). The L1 carrier is phase-modulated with two binary pseudorandom-noise codes that contain GPS information: (1) the coarse-acquisition (C/A) code, characterized by a chip rate of 1.023 MHz and (2) the precise (P) code, characterized by a chip rate of 10.23 MHz and modulated in quadrature with the C/A code. The L2 carrier is modulated with the P code only. The signals from different satellites are distinguishable from each other because each satellite transmits a unique C/A and a unique P code. Although the limitation on space also precludes a detailed description of the C/A and P codes, it can be said here that names of these codes convey an approximate idea of the roles played by these codes and of the relationship between them. The C/A and P codes of all the satellites are further modulated with a common binary code that conveys information about the satellites, their orbits, their clock offsets, and their operational statuses.

The basic principle of GPS receiver signal processing is to determine the time and the position of the GPS receiver from times of arrival of signals transmitted from several different GPS satellites. This basic principle is implemented, in practice, by use of correlations between (1) the received GPS signals and (2) model signals in the receiver